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I. Introduction

Improvised rocket motors provide a simple means for irregular forces to deliver military payloads to ranges beyond individual hand weapons without complicated launch means. Improvised rocket techniques can be exploited to increase the firepower and effectiveness of guerrilla-type forces. Having the great advantage of not requiring heavy launching equipment, such as conventional mortars and artillery pieces, rockets are aptly suited to the characteristics of operations and capabilities of irregular units whose weapons must be concealed between use and whose transport and logistics means are restricted to that common to the area of operations.

The advantages of an improvised rocket munition are:

A. Recoilless operation.

B. Simplified launching techniques and apparatus. (A mound of dirt may suffice in the simplest case.)

C. High degree of mobility. (Only the payload, motor and ignition device need to be carried.)

D. Munitions can be fabricated from materials available from the environment or the local economy.

E. Unskilled labor can be used for manufacturing operations.

F. The identity of the manufacturing effort can be easily concealed.

This report will investigate a system using and providing the following features:

A. Use of common materials for construction (pipe, pipe caps and nipples; saltpeter and sugar; wooden dowel, et cetera).

B. Recoilless, flashless performance.

C. Adaptability to a wide spectrum of payloads and ranges.

D. Suitable for a variety of ignition means including powder train, hot wire, blasting fuse or homemade fuse.

E. Capability of being fired remotely or with a minimum of 20 seconds delay for operator security.

F. Capability for instantaneous firing of multiple round salvos or single rounds (for harassment or ranging).

G. Establishment of a relatively "standard" rocket carrier design, determined from the materials available in the particular area. (This will simplify the ballistics and provide the forces with a predictable weapon.)

Section II, "Technical Discussion", describes the analysis and design approach to be used in providing the improvised hardware. It also outlines the problem areas and considerations in providing reasonably useful munitions in a surreptitious fabrication situation where quality control and manufacturing processes must be accomplished without tools other than common hand tools and "eye ball" instrumentation.

II. Technical Discussion

A. BACKGROUND

In the period 1947 to 1957, a large number of amateur rocket experimenters were engaged in the manufacture and testing of rudimentary rockets. By 1947, the information from the World War II rocket technology began to become documented and disseminated, catching the imagination and interest of many young experimenters. These persons, working alone or banding into groups, produced many hazardous, and even lethal, rocket propelled missiles. Unfortunately, the hazardous nature of the propellants selected, such as match heads, shotgun shell powder, and home-brewed mixtures of volatile and inflammable materials, proved more dangerous in the basement or garage laboratory than on the firing range. The large number of injuries from the uncontrolled experimentation led to many local ordinances and laws prohibiting the sale of certain materials and also restricting the firing activities to areas where adequate supervision could be provided. This general awareness of the hazards of rocket experiments began about 1957, evidenced by the American Rocket Society adopting an official organizational position opposing amateur experimentation outside of qualified supervision. In spite of the restrictions, the experimenters still found common materials which could be adapted to produce rocket hardware.

During the decade of more or less widespread amateur experimentation in rocketry, many combinations of propellant formulations were made and tested. Ingenious experimenters devised ways of extracting nitrates from the cheap and readily available fertilizers having this compound. Mixing this source of oxygen with various fuels provided very adequate rocket propellants. One of the materials found to

be readily accessible was sugar. A sucrose-potassium nitrate formulation provides a specific impulse (as derived from ballistic bomb data) of about 130 - 140 seconds. In actual rocket motor performance on the order of 105 seconds is readily attainable. This compares with an I_s of 200 for M-7 propellant, currently in wide use in military rockets.

In preparing this book several pipe rockets were assembled and tested against wooden targets at short range, demonstrating the feasibility of the propellant and body structure.

This study proposes sucrose-potassium nitrate for the improvised rocket propellant. Both these materials can be obtained in most of the world, particularly in those areas where insurgency operations are most probable. These designs for an improvised rocket will concentrate on this propellant mixture as the "standard."

In providing an improvised munition of this type, this study will give attention to the following areas:

A. Propellant grain formulation and configuration.

B. Grain installation in rocket body for integrity in rough handling, storage life expectancy and reliability in handling.

C. Assessment of environmental effects such as operating temperature ranges for various possible geographical areas, humidity and fungus.

D. Safety.

E. Training.

F. Effects of variations in materials of construction on safety and performance.

G. Security Aspects

Means should be provided to conceal the true nature of the items being fabricated.

H. Launching preparation should be simple allowing rapid setup and firing.

I. Signature effects at the launch site should be minimum.

J. High reliability of operation should be obtained to avoid problems of disposal of duds.

Our effort will provide:

A. Specific hardware designs and sample prototype units of rocket motors of simple design constructed from common materials such as would be readily available to guerrilla-type forces.

B. Generalized design guidance for instruction of guerrilla personnel in the construction of improvised rockets, including safety precautions.

C. Descriptions of firing procedures, including rudimentary ballistics and fire control under probable conditions of use.

D. Investigation of reliable ignition methods. Also, means for ignition of the improvised rockets for firing individual rounds and salvo or ripple firings of multiple rounds.

E. Report of effects obtainable from the improvised rounds, including: range, payload, probable dispersions under standard and non-standard conditions and possible type payloads.

F. Prediction of degradation in performance from optimum due to fabrication variances, materials impurity, field handling, storage and environmental conditions.

B. DESIGN CONSIDERATIONS

This study's proposed design will be based upon rockets using materials obtained from normal agricultural, construction or commercial sources. Referring to the early work done by the amatuer groups in the practical application of rocket design theory to their hardware, their experience indicates that some experimental verifications and detailing is required before scale-up of their small diameter rockets (½ to ¾ inch water pipe bodies) to militarily useful diameters (minimum of 2 inches). These include:

A. Length to Diameter (L/D) Ratio

A certain maximum (L/D) ratio cannot be exceeded without generation of excessive chamber pressures, which can rupture the chamber wall.

B. Propellant "Watering"

A certain content of water is necessary for efficient performance. This has been referred to as an "aid for compaction" by some amateur groups, but the real mechanism affecting performance must be determined.

C. Port Diameter to Nozzle Diameter

The usual rule, that the port area must be two to three times the nozzle area does not seem to hold rigorously for the rather soft, crodible grain formed by KNO_3/sugar. This should be investigated.

D. Effective Burning Area To Throat Area (K_n)

Attempts have been made by the amateurs to correlate various working geometries by K_n. Attempts indicated that a probable mass-action or permeable burning effect makes this relationship not wholly straightforward. This will have to be definitized before motors larger than two inches can be designed.

Data is on hand from the firings of over a thousand rockets assembled and fired by a group of private experimenters comprising a rocket research association, now disbanded. This group, although using rudimentary materials for construction, maintained their records of fabrication and testing in a professional manner and in sufficient detail to reproduce their designs. The bulk of the (more than a thousand) units prepared by this group were rockets fashioned from standard ½ inch and ¾ inch pipe. It is believed that similar designs can be scaled upward to provide rockets of two inch diameter having a maximum range of 4,000 meters carrying a one pound payload, or correspondingly shorter ranges for greater sized payloads.

C. DESIGN CONFIGURATION AND PERFORMANCE

A ".62 standard" (.62" is the inner diameter of common ½ inch water pipe) motor has been fabricated and test units fired with piezo-electric gauges attached. Burning times are much shorter and thrust levels higher than performance of the propellant in amateur testing has indicated. However, the total impulse seems to agree quite well. On the basis of these tests, a set of curves was drawn to show payload delivery capabilities for the ".62 standard" and also a ".82" motor (¾ inch pipe). These curves are shown in Figure 1.*

A one pound payload, as an example, can be projected to 600 feet with a .62 motor and more than 1,500 feet with a .82 motor. Extrapolating to a two inch pipe motor gives a range of nearly 12,000 feet for a one pound payload.

A conceptual drawing of an improvised rocket motor embodying the concepts outlined in this proposal is shown in Figure 2.

Figure 3 shows the procedure for loading KNO_3/sucrose propellant. After compacting the grain with the hollow tamper, the mandrel (dowel) is removed to leave the perforated grain.

D. DEVELOPMENT PROGRAM

In providing an improvised rocket concept, this study proposes:

A. Examination of basic design models to establish definitive criteria involved in predictable scaling of motors to meet variable diameters and characteristics of possible body construction materials.

B. Performance of testing to validate and formalize the scaling laws.

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* *Although pipe sizes in a given area of employment may not be identical with standard U.S. pipe dimensions, performance should be comparable.*

Curves are computed from the equation given in Paragraph E with the total impulse obtained from actual rocket tests.

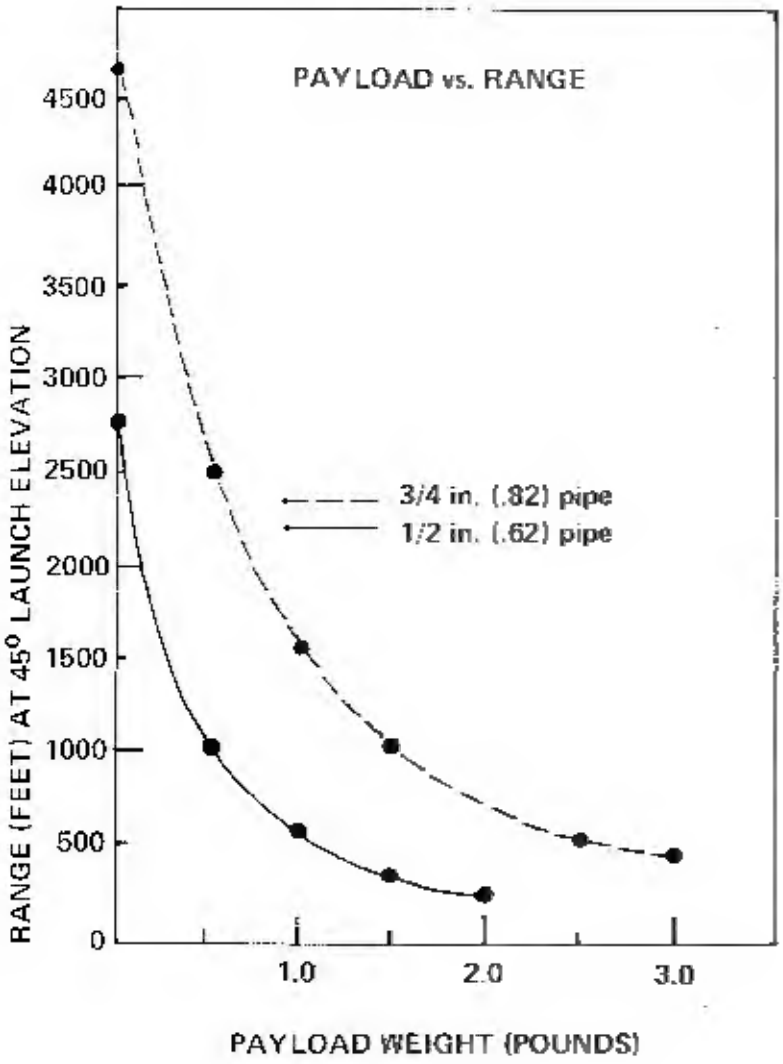
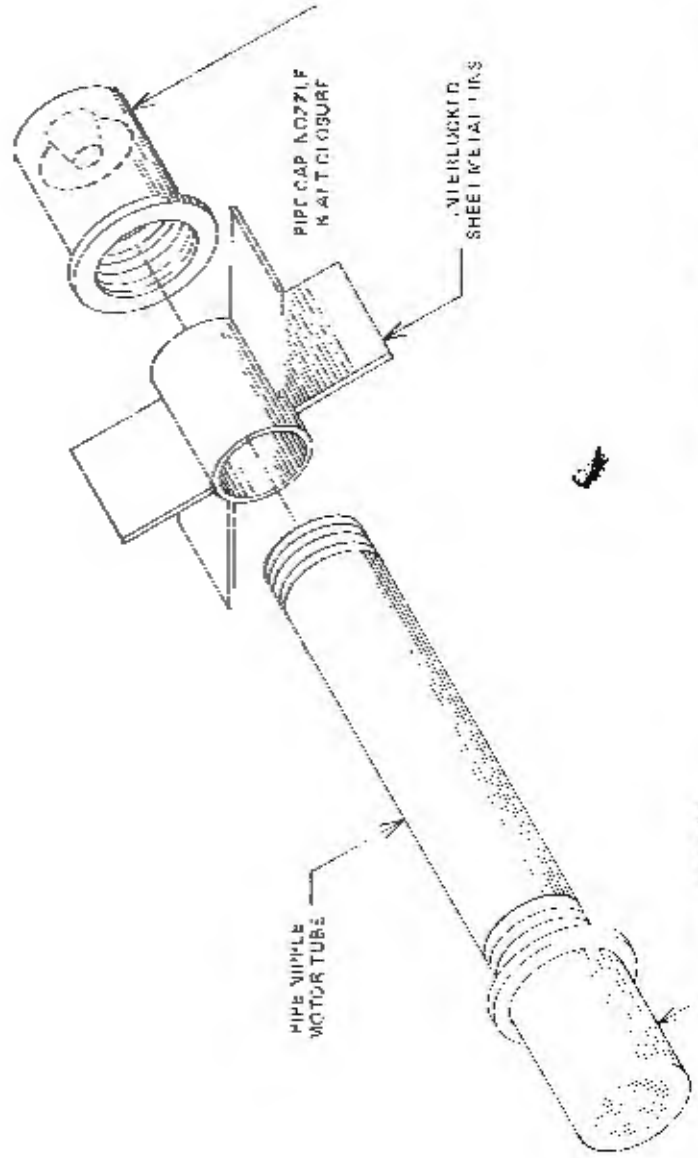


Figure 1



IMPROVISED ROCKET MOTOR
Figure 2

LOADING TECHNIQUE
For Improvised Rocket Motor

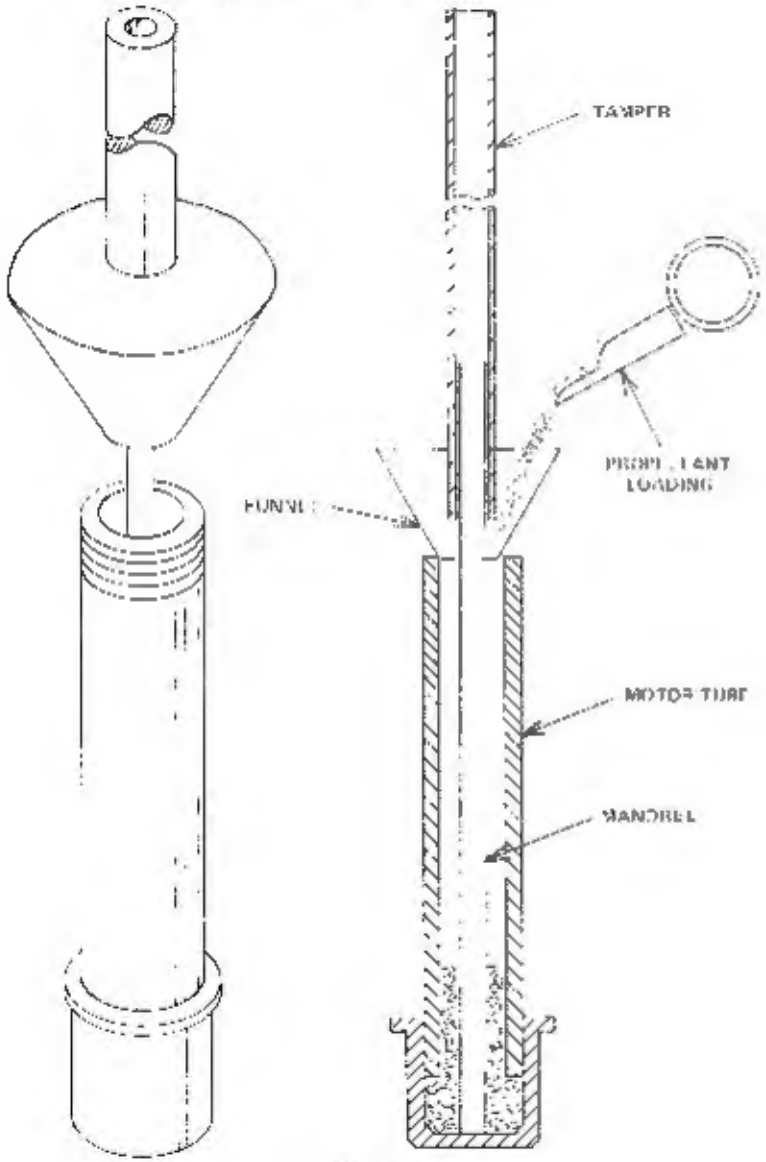


Figure 3

C. Design and development of a typical improvised rocket motor suitable for construction by unskilled personnel using commonly available materials and tools.

D. Fabrication of 65 each prototype pipe-bodied rockets (all loaded with KNO3/sugar propellant), of the following pipe sizes:

1/2 inch
3/4 inch
1-1/2 inch
2 inch

E. Test firing of the above units, expending 25 of each type in static tests for characterization and 40 each in payload versus range tests, with 1/2 to 1 pound inert heads. Impact pattern data will also be collected for an indication of dispersion.

F. Preparation and submittal of a final report describing the designs, fabrication procedures for field accomplishment, firing and launching procedures, safety measures and the program activity accomplished during the program. A supplement will be prepared for the improvised weapons handbook for each size rocket motor tested and range tables provided.

In addition to the basic rocket carrier, it is proposed that a study be made of the employment of the rocket as a practical weapon, including possible payloads and the implications and interface considerations between the payloads and the rocket. The effort will include:

A. Study and design of ignition means for individual and multiple round firings, including delay provisions.

B. Payload interface investigations, including recommended payloads, methods of attachment, arming and activation, performance characteristics and modifications required to adapt rocket and payload.

E. PERFORMANCE OF POTASSIUM NITRATE/SUGAR PROPELLANT

A composition of 70% Potassium Nitrate Technical Grade, 100 80 mesh (Tyler) with 30% sucrose, commercial grade, crystalline, plus 3-5% water to aid in compaction for grain fabrication (internal burner only) has been tested in ballistic bombs, providing the following data:*

Assuming a molecular weight (MW) = 30

Ratio of specific heats (k) = 1.21

Temperature of combustion (T_c) = 2640°R

Gives a specific impulse (I_s) = 137 sec (500 psi → 15 psi)

In a particular motor, the following determinations were made:

Characteristic exhaust velocity (c*)	= 3080 fps
I_s	= 105 sec
With a thrust coefficient (C_F)	= 1.10
At a propellant density	= 0.05 lb/in^3
Burning rate (r_b)	= 0.28 in/sec (at 800 psi)
Lower limit, combustion chamber pressure (P_c)	= about 100 psi
Upper limit, P_c	= more than 7500 psi

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* *Although commercial purity materials may not be available to field forces, standard materials are cited here for reference and later comparison with actual results obtained. The degradation of performance from the use of "field grade" purity compositions will be investigated. It is possible, however, that materials can be obtained in pure form, thereby achieving optimum performance.*

The performance of this propellant, then, is slightly superior to black powder. The specific impulse derived from motor data was used to compute the range versus payload graph of Figure 1 as follows:

$$\text{Range at } 45^\circ \text{ elevation} = \frac{1}{g}\left[\frac{I_T\, g}{w_m + w_p + \frac{w}{2}}\right]^2$$

Where: g = gravitational acceleration 32.2 ft/sec^2

I_T = total impulse, lb-sec

= specific impulse x propellant weight

w_m = weight of motor, lbs

w_p = weight of payload, lbs

w = weight of propellant, lbs

F. PAYLOADS AND MISSIONS FOR IMPROVISED ROCKETS

Once the basic propulsion unit is available, only the ingenuity of the guerrilla personnel limits the possible missions for the rockets. A number of payloads are immediately suggested, ranging throughout the spectrum of regular munitions. Possible missions are shown in Figure 4.

There are some types of payloads such as incendiary mixtures and biological materials which can be put together quickly by the guerrilla fighter, for example, the Molotov cocktail mixture.

It would be possible to assemble improvised "tomato can" munitions for use with the improvised rocket. High explosive charges, surrounded by available small hardware such as nails and bolts could be prepared for delivery with the improvised rocket.

IMPROVISED ROCKET MOTOR MISSIONS

OFFENSIVE OPERATIONS
- Antipersonnel
  - Grenade throwing (shrapnel, concussion, tear gas)
- Antivehicular
  - Shaped charge
- Antistructural
  - Shaped charge
- Antiaircraft
  - Ripple firings or simultaneous launch of rockets carrying aloft trailing wires
- Sabotage
  - Remote firing of pre-positioned and concealed units into a secured area
  - Projection of conductors over high tension lines or into transformer stations to short out service circuit

SUPPORT MISSIONS
- Line Throwing
  - Access across obstacles
  - Projection of telephone wires between two friendly positions
- Signaling
  - Projection of flares and smoke
  - Projection of message containers

Figure 4

It is assumed that the guerrilla forces will be armed to some degree with conventional weapons, particularly hand guns and grenades. The most effective payload for the improvised rocket is the grenade: the proposed primary mission is as a grenade thrower. Available in a variety of fillings, the grenade provides a reliable, self-contained unit easily affixed to the improvised rocket carrier by insertion in an open ended can fastened to the rocket head cap. The can would be of a size to allow pulling of the grenade safety pin while restraining the hand safety clip of the U.S. type grenades. Air drag during flight can be used to separate the grenade from the can, or the grenade can be arranged to separate (and arm) at ground impact. Other arming innovations can be devised for friction match (pull type) igniters of some foreign grenades.

The improvised rocket's great advantage is that it can be made in moderate numbers quickly with ordinary hand tools, or its parts can be pre-fabricated and stored as partially finished stock, presenting the appearance of some unsuspicious commercial product. When needed, the units can be loaded rapidly and assembled into the tactical configuration. Payloads can be affixed and even final assembly can be accomplished under cover or concealment at or near the launch site. Components can be brought into the assembly area by separate persons for security of the operation and personnel. A typical launch area setup showing a powder train ignition method is depicted in Figure 5. The circular launch configuration and the central origin for powder trains to each rocket allows ripple firings without one rocket exhaust extinguishing the powder train of adjacent rockets. The launch support shown in Figure 5 is a simple forked stick cut to a size to allow the 45° launch angle. This is accomplished by providing the vertical height of the support to be 7/10th of the length of the rocket body to the point of support.

In addition to stick supports, mounds of dirt, convenient embankments, drain pipe or stove pipe, wooden troughs or a variety of other materials as available in the area can be used for rocket positioning and initial directional control.

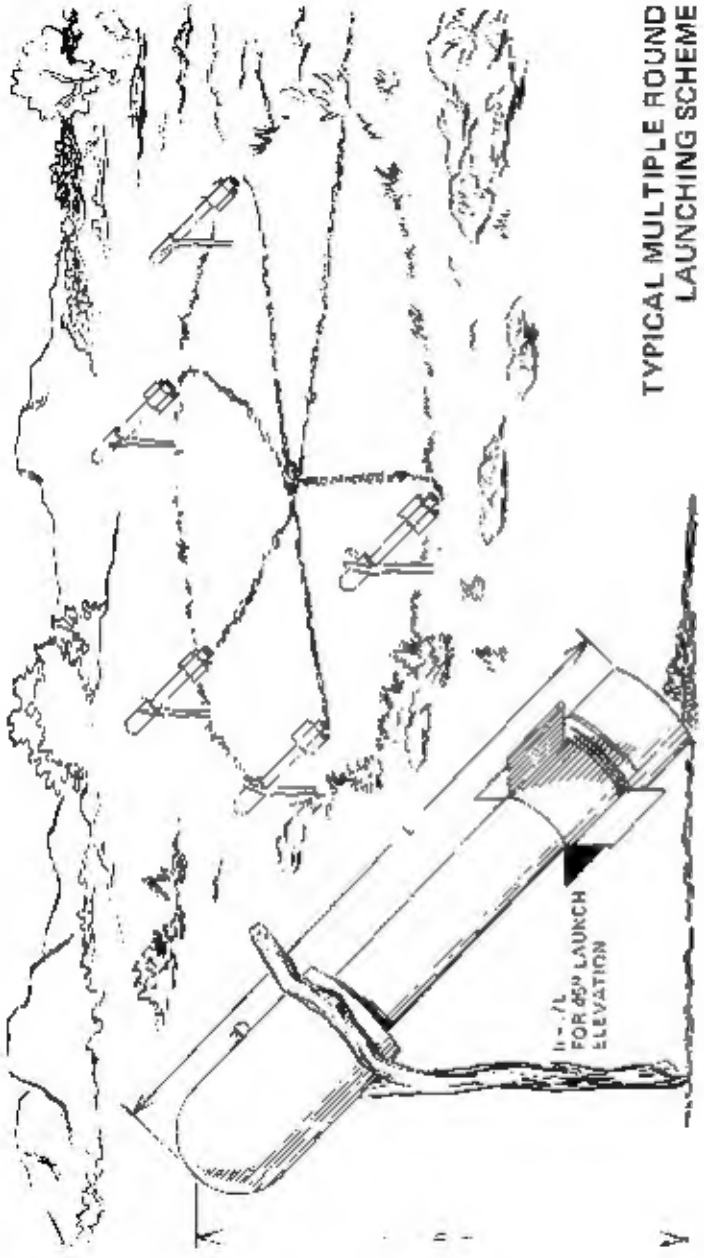


Figure 5

Figure 6 shows examples of ignition means which can be used for firings of individual or multiple rounds.

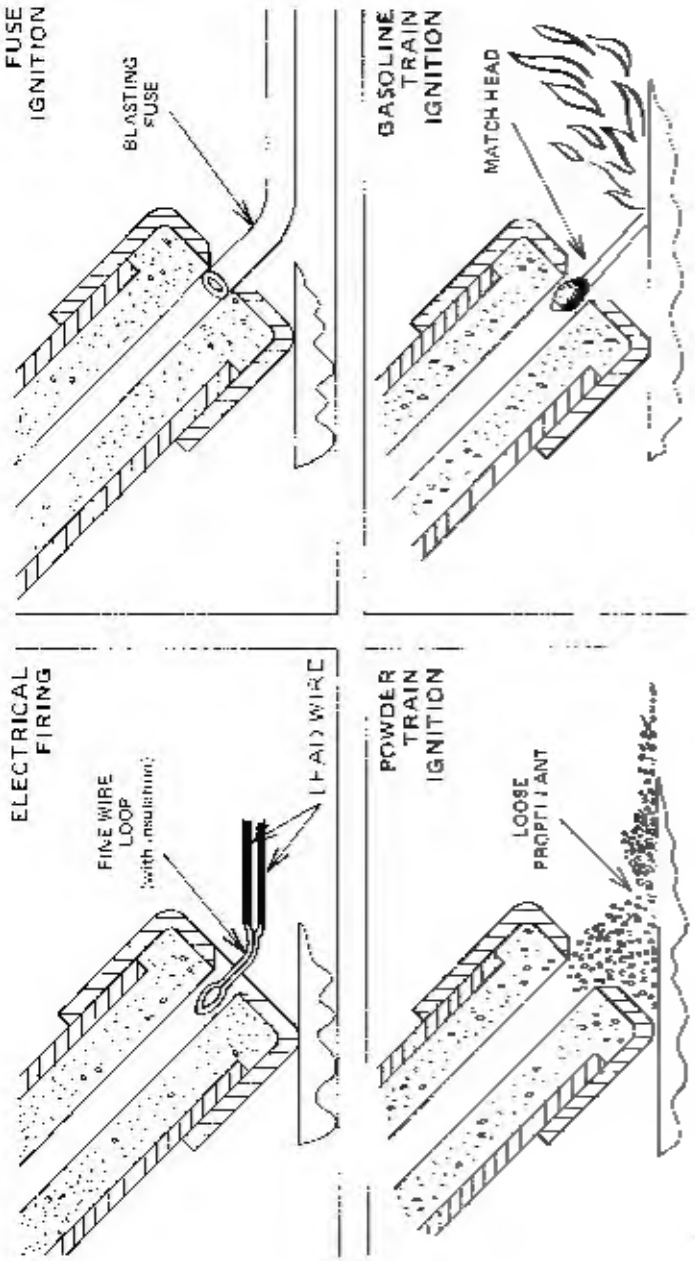
G. TACTICAL EMPLOYMENT

Although the improvised rockets are of relatively small size, they can be used for projecting relatively heavy payloads for short distances. For example, they might be used as anti-vehicular or even anti-tank weapons. In such use, the rocket would be pre-positioned with its warhead and ignited remotely. A typical emplacement might be in an embankment flanking a defile or road traveled by vehicles. A very large warhead could be projected on a relatively flat trajectory for a range of 10-30 meters.

The fabrication of shaped charge devices is readily accomplished in the field. For example, the bottom configuration of many wine bottles forms an excellently configured mold and liner for a shaped charge. It is also possible to improvise an impact initiator using sodium chlorate, sugar and sulphuric acid (car battery acid).

The possible use of the improvised rockets as antiaircraft weapons should not be discounted. Arranged in arrays under the approach or take-off patterns of airports, or pre-positioned in probable landing areas for aircraft or helicopters, the improvised rocket could prove a reasonably effective one time weapon. It would also be possible to use the rockets for air defense of an area by launching salvos against pre-selected points in the airspace over the guerrilla position, firing the rockets upon the approach and passage through the airspace by the target aircraft.

An interesting mission for individual rockets is in the throwing of lines. A large variety of uses is possible here. In acts of sabotage, conductive wires can be projected over high tension lines or into transformer stations to short out circuits of the electrical supply. Since critical electrical facilities are likely to be under close security guard or surveillance, an ability to reach the installation by rocket fired from a secure point outside the security area provides access which might otherwise be impossible for the saboteurs.



IGNITION METHODS
Figure 6

The same wire pulling technique can be used for friendly support purposes — to interconnect two positions with telephone cable or to place a lead line across an obstacle to draw across a heavier interconnection for further access across the obstacle.

The improvised rocket would be best employed with payloads and missions which exploit the basic features of the improvised device. These missions are:

A. Grenade throwing for anti-personnel and limited structural damage.

B. Line throwing for access into secured areas or in spanning obstacles.

The guerrilla force having a rocket capability will find missions for its employment to meet many needs arising in their environment. They will use both individual rockets to solve specific access problems and multiple round firings for their defensive and offensive operations. The improvised rocket will add a shock and surprise capability to insurgent operations. It will give the agents not only greater striking opportunity but better security and ability to escape after actions. Once used by the guerrilla force, rockets will expand the opposition's manpower required for the security of vital installations, making the counter-insurgency effort more burdensome and costly.

The improvised rocket will add a dimension to guerrilla operations impacting both the tactical and psychological areas of the insurgency situation. The rocket capability will strengthen the effectiveness and morale of the guerrilla force, while presenting the opposing authority with a new and unexpected problem. Increased suppressive effort over larger areas must be applied to counter the suddenly increased vulnerability of his installations, equipment and personnel. At a very low cost to the guerrilla in time and effort, his harassment value will be enhanced significantly through addition of the improvised rocket to his "arsenal".

APPENDIX

Table I, following, gives the results of more than 1,000 test firings of potassium nitrate/sucrose propelled rockets using a propellant formulation as described in Paragraph E, Section II, "Technical Discussion". Tests were conducted during the period 1947-50. Notation used on Table I follows the conventions outlined in the section following the Table: "Simple Expressions For Quick Look Estimations of Solid Propellant Rocket Motor Performance".

SUMMARY OF ROCKET MOTOR TESTS WITH KNO_3/SUCROSE PROPELLANT

GRAIN					K_n	$F_{Lbs.}$	C_F	Number of Nozzles	P_c Lbs./In.^{2}
TYPE	O.D.	I.D.	LENGTH	WEB					
Restricted End-Burn.	1.93	No Perforation	13	13	14	-	-	5	-
Circular Perforation	.622	.25	6	.136	191.3	35	1.10	1	1,300
Circular Perforation	.622	.25	6	.136	170.8	35	1.10	5	1,150
Circular Perforation	.622	.1885	6	.217	143.8	37.5	1.10	1	1,385
Circular Perforation	.622	.1885	6	.217	128.1	37.5	1.10	5	1,232
Circular Perforation	.93	.25	12	.340	123.0	-	-	1	-
Restricted End-Burn.	.824	No Perforation	4.7	4.7	19.6	4	-	1	135
Circular Perforation	.824	.40	10	.212	128.2	58	1.21	5	490
Circular Perforation	.824	.40	10	.212	110.0	42	1.21	1	314

SIMPLE EXPRESSIONS FOR QUICK-LOOK ESTIMATES OF SOLID PROPELLANT ROCKET MOTOR PERFORMANCE

Basic Equations

$$F = A_t P_c C_F = A_b \rho_s r_b = \frac{I_T}{t_b} = I_s \dot{w}$$

$$I_s = \frac{c^* C_F}{g} = \frac{I}{t_b \dot{w}} = \frac{F}{\dot{w}}$$

Typical Values For Solid Rocket Parameters

	Potassium Nitrate	Ammonium Nitrate Composite	Ammonium Perchlorate Composite	Aluminized Composite	Potassium Perchlorate	Double Base
1.25 can be used as a k value for all propellants						
r_b(in/sec) 1,000 psi	.25	.1	.20	.25	1.5	1.6
I_s 1,000 psi	130	150	200	235	180	220
	500 psi	1,000 psi	1,500 psi	8,000 psi		
C_F	1.46	1.55	1.60	1.65	Note: Max C_F = 2.248	
c	5	7	10	18		

CLOSED BOMB DETERMINATION OF SPECIFIC IMPULSE:

Bomb Volume = V, cc

Propellant Weight = w, gm

Maximum Pressure = P, lb/in^2

Impetus = F_{imp} ft-lb/lb

$$F_{imp} = k_1 \frac{P}{w/V}$$

k_1 = 2.307 (covolume and dimensionless unit conversion factor)

$$c^* = k_2 (F_{imp})^{1/2}$$

k_2 = 7.72 (unit conversion factor)

$$I_s = \frac{c^* C_F}{g} = K_3 C_F (F_{imp})^{1/2}$$

k_3 = 0.240 (dimensionless factor)

$$I_s \text{ 1,000 psi} = k_4 (F_{imp})^{1/2}$$

k_1 = 0.379 (unit conversion factor)

NOTE: Constants k_1, k_2, k_3 and k_1 above are empirically derived factors which give approximations to the quantities expressed for quick look evaluations of the proposed solid propellant rockets as derived from amateur group experiments.